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THE 2010 M 87 VHE FLARE AND ITS ORIGIN: THE MULTI-WAVELENGTH PICTURE

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for the H.E.S.S., MAGIC, VERITAS and FERMI-LAT COLLABORATIONS and
THE M 87 MWL MONITORING TEAMS

The giant radio galaxy M 87, with its proximity (16 Mpc) and its very massive black hole ($(3-6)\times 10^9\,M_\odot$), provides a unique laboratory to investigate very high energy (E>100 GeV; VHE) gamma-ray emission from active galactic nuclei and, thereby, probe particle acceleration to relativistic energies near supermassive black holes (SMBH) and in relativistic jets. M 87 has been established as a VHE γ-ray emitter since 2005. The VHE γ-ray emission displays strong variability on timescales as short as a day. In 2008, a rise in the 43 GHz Very Long Baseline Array (VLBA) radio emission of the innermost region (core; extension of $< 100 R_s$; Schwarzschild radii) was found to coincide with a flaring activity at VHE. This had been interpreted as a strong indication that the VHE emission is produced in the direct vicinity of the SMBH. In 2010 a flare at VHE was again detected triggering further multi-wavelength (MWL) observations with the VLBA, Chandra, and other instruments. At the same time, M 87 was also observed with the *Fermi*-LAT telescope at MeV/GeV energies, the European VLBI Network (EVN), and the Liverpool Telescope (LT). Here, preliminary results from the 2010 campaign will be reported.

Keywords: galaxies: active – galaxies: individual (M 87) – gamma rays: observations – galaxies:jets; nuclei – radiation mechanisms: non-thermal.

1. Introduction

The giant radio galaxy M 87 provides a unique environment to study relativistic plasma outflows and the surrounding of supermassive black holes (SMBH). Its prominent jet[1] is resolved from radio to X-rays, displaying complex structures (knots, diffuse emission,[2,3]), strong variability[4,5], and superluminal motion[6,7] (Fig. 1[8]). With its proximity

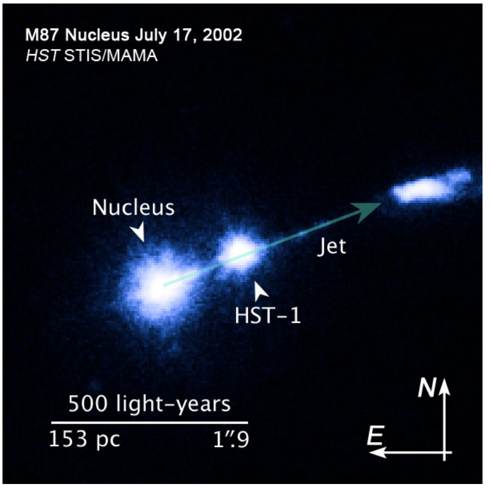

Fig. 1. Hubble Space Telescope (HST) image of M 87. *(Illustration Credit: NASA, ESA, and Z. Levay, STScI; Credit: NASA, ESA, and J. P. Madrid, McMaster University)*

(16.7 ± 0.2 Mpc;[9]) and its very massive black hole of $M_{\mathrm{BH}} \simeq (3-6) \times 10^9\,\mathrm{M}_\odot$[10,11] high-resolution radio observations enable one to directly probe structures with sizes down to < 200 Schwarzschild radii.

M 87 has been established as a very high energy (VHE; $E > 100$ GeV) emitter since 2005[12,13]. It is one of only four extragalactic VHE sources belonging to the class of radio galaxies for which only weak or moderate beaming of the emission is expected. M 87 shows strong variability at VHE with timescales of the order of days[13,14,15]. This indicates a compact emission region $< 5 \times 10^{15} \delta$ cm (δ: bulk Doppler factor of the emitting plasma), corresponding to only a few tens of Schwarzschild radii. M 87 has recently been detected at GeV energies by *Fermi*-LAT[16].

The angular resolution of ground-based VHE instruments[a] does not allow for a direct determination of the origin of the VHE emission in the inner kpc structures. To further investigate the location of the VHE emission site and the associated production mechanisms, variability studies and the search for correlations with other wavelengths need to be utilized[15].

Up to now, three episodes of enhanced VHE activity have been detected from M 87. The first one, in 2005[13], occurred during an extreme radio/optical/X-ray outburst of the jet feature HST-1[4,5], which has been discussed as a possible site for the VHE emission[7,17,18]. During the second flaring episode, in 2008, HST-1 was in a low flux state, but radio measurements showed a flux increase of the core region within a few hundred Schwarzschild radii of the SMBH, suggesting the direct vicinity of the SMBH as the origin of the VHE emission[15]. This conclusion was further supported by the detection of an enhanced X-ray flux from the core region by *Chandra*.

[a]Typically, ~0.1 degree per event, corresponding to ~ 30 kpc projected size.

The third episode of increased VHE activity occurred in 2010 during a joint VHE monitoring campaign by MAGIC and VERITAS. The detection of the high state[19,20] triggered further multi-wavelength (MWL) observations by the VLBA, *Chandra*, and other instruments. Preliminary results from the campaign are presented in this paper, while the final campaign results will be reported in an upcoming publication.

2. The 2010 VHE flare

The preliminary combined VHE light curve for the 2010 monitoring campaign is shown in Fig. 2 upper panel. During the campaign, two episodes of enhanced VHE γ-ray emission have been detected[19,20]: The first episode took place in Feb. 2010, where a single night of increased activity was detected by MAGIC. VHE follow-up observations did not reveal further activity. The second episode took place in Apr. 2010 and showed a pronounced VHE flare detected by several instruments, triggering further MWL observations.

The VHE activity of this second flaring episode is concentrated in a single observation period between MJD 55290 and MJD 55305 (~15 days). This time period is exceptionally well covered by observations with 21 pointings by H.E.S.S., MAGIC, and VERITAS, resulting in an observation almost every night. The detected flare displays a smooth rise and decay in flux with a peak around MJD 55296 (April 9-10, 2010; see Fig. 2). In general, during nights with quasi simultaneous observations by different instruments, the measured fluxes are found to be in excellent agreement.

Compared to previous VHE flares detected in 2005 and 2008, the 2010 flare shows similar timescales and peak flux levels, but the overall variability pattern is somewhat different (more extended periods of flaring activity with several flux maxima), though the statistics and the sampling of the previous VHE flares limit a definitive conclusion.

3. 2010 multi-wavelength observations

The discovery of a VHE high state in April 2010 triggered further multi wavelength (MWL) observations, which are displayed in Fig. 2.

Chandra started observing two days after the peak VHE flux had been detected, performing five pointings spaced in intervals between 1.5 and 3 days (5ks each). A second set of four observations was taken starting about two weeks later. HST-1 was found in a low flux state, while the core showed an increase in X-ray flux in the first observation that followed the VHE flare. Further details on the *Chandra* observations can be found in Harris et al. in these proceedings.

A total of five VLBA 43 GHz observations were taken in 2010, three monitoring observations and two additional observations following the detection of the VHE high state. No enhanced radio flux from the core region was detected, contrary to what was observed during the 2008 VHE outburst[15].

During the 2010 campaign, further MWL data were taken by the Liverpool Telescope in the optical, the EVN, and the VLBA, and M 87 was continiously monitored at MeV/GeV energies with the *Fermi*-LAT. No significant variability is found in the 2 year *Fermi*-LAT

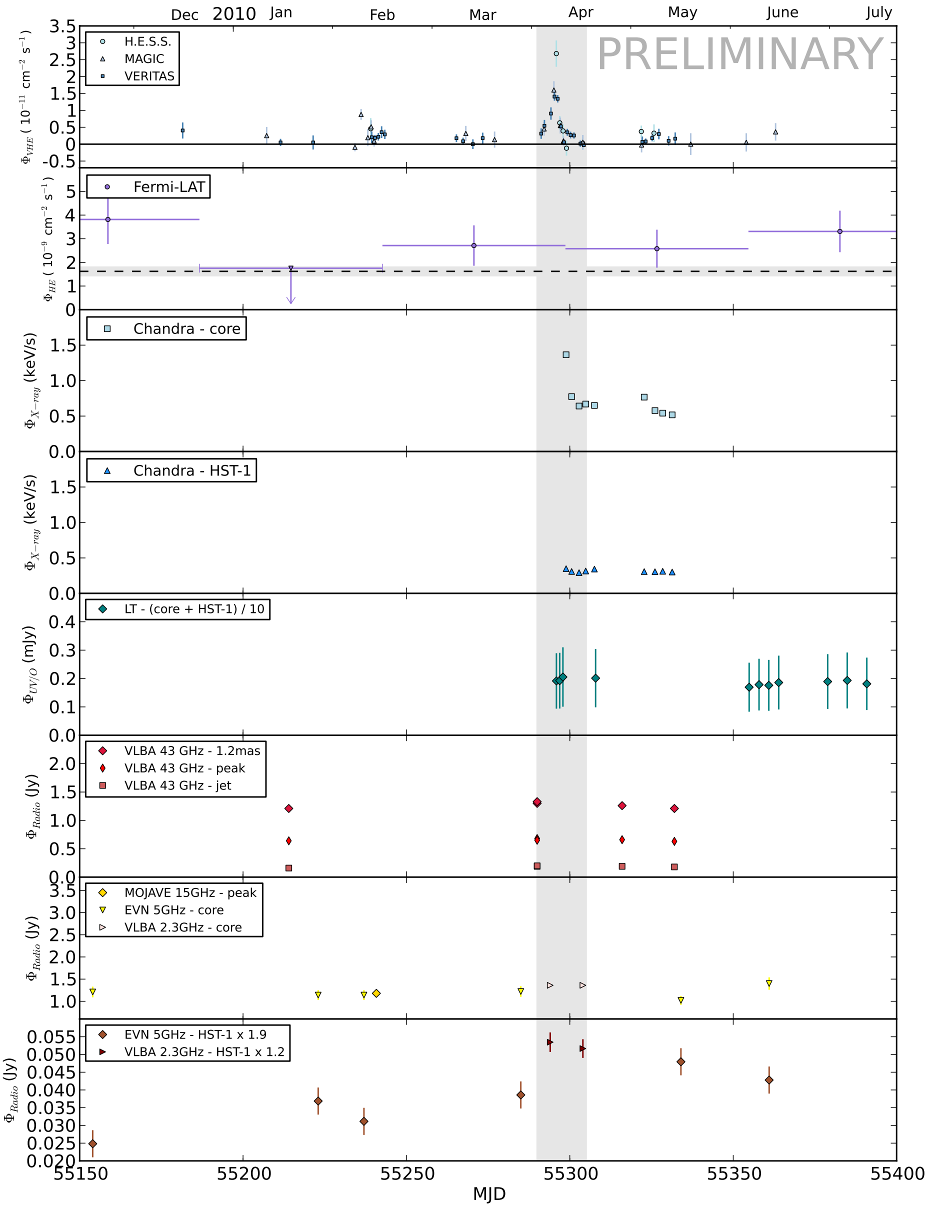

Fig. 2. Preliminary MWL light curve from the 2010 monitoring campaign on M 87. The integral fluxes in the VHE range are shown above an energy of 350 GeV. The radio flux of HST-1 at different frequencies has been normalized to the 5 GHz flux assuming a spectrum $S_\nu \sim \nu^{-\alpha}$ with $\alpha = 0.6$. More details on the data sets, analysis, and the characteristics of the different instruments can be found in an upcoming publication.

data set spanning from August 2008 to August 2010. The details of these observations will be reported in an upcoming paper.

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